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INTRODUCTION

Recycling is nothing new under the sun, even in economic systems. All interdependent groups of biota, whether comprising an economy or an ecosystem, facing some kinds of resource limits, reuse at least some of the wastes they produce. For example, in an ecosystem the wastes of animals through a complex series of biological and chemical processes are returned as nutrients to living plants. Otherwise they would escape the bounds of the ecosystem or poison it if allowed to accumulate. Similarly, in our economy scrap iron and other recycled metals still contribute a significant share of raw inputs for metals manufacture.[1]

Indeed, at any point in time a biological or economic system strikes a balance between waste throughput[2] and waste recycling activity. In a biological system, such an equilibrium point is found with a view towards survival and balance among the constituent natural organisms. An economic system, at least in theory, chooses a mix of recycling and throughput activities in accordance not only with basic human biological needs, but also with maximization of social satisfaction, which depends on a lot more than nutrient flows. Recently, however, many non-economists have come to the conclusion that our economic system recycles insufficiently to spare us the grim consequences of solid waste pollution and resource exhaustion.[3] The purpose of this article is to investigate why the economy recycles as little as it does and whether an economic rationale exists for promoting more recycling activity.

ECONOMIC SYSTEMS AND ECOSYSTEMS: SIMILARITIES AND DIFFERENCES

Understanding the economics of recycling requires us to make some comparisons between economic systems and ecosystems. Ecosystems have two man components: "living organisms and their non-living environment."[4] Their relationship is one of interdependence; green plants consume basic organic and mineral nutrients contained within the ecosystem, raising the energy level of the resulting transformed nutrients via photosynthesis. Such plant nutrients become the food supply for plant-eating animals (herbivores), whose biomass in turn supports a more limited population of flesh-eating animals (carnivores). Wastes and organic detritus from the living sphere of the ecosystem are reconverted to original soil nutrients by scavenging organisms and processes, returning to the food chain when re-energized by plants. Energy fixed by plants, however, is ultimately dissipated as it passes through the food chain.

Populations of the various organism groups are kept in balance by three factors: (1) the available supply of nutrients; (2) the populations of predators and prey; and (3) the incoming flow of energy. For example, the population of carnivores is regulated by the number of herbivores they can prey upon, which is in turn dependent on both the supply of edible plants and the predator population that feeds upon them. Finally, the volume of plant biomass is controlled by herbivore feeding, available soil nutrients (humus and minerals) and incoming solar energy.

Parallels can be drawn with an economic system by reference to the interdependent workings of an input-output table. For example, the volume of automobiles that can be manufactured annually is a function of the production levels of steel, rubber, plastics, etc. Reversing the situation by assuming that demand expansion is the driving force in inter-industry relationships, an increase in demand for automobiles leads to an increase in demand for the products of suppliers to auto manufacturers. Such raw material producers in turns transmit a series of demands to their suppliers until after theoretically many iterations a new economic equilibrium is struck. This new set of increased output volumes would be arrived at by a similar series of events to that which would occur in an ecosystem as a result of an unprecedented expansion in available plant biomass caused by some exogenous factor. Herbivore populations would increase, allowing in turn carnivore populations to grow.

The most important basis of comparison between economy and ecosystem involves recycling. Let us examine more closely the similarities and differences concerning the orientation of each system to waste reuse. First of all, an ecosystem in static equilibrium is not living off an endless cornucopia of external nutrients. Only energy comes from without. Were an ecosystem a throughput system it could not survive, nor could any of its components. Each organism absorbs those nutrients which it can biologically utilize; it cannot recycle its individual wastes. Hence it would soon exhaust its nutrient sources were they not being continuously replenished in some manner. Since such nutrient sources must be from within the ecosystem, it follows that they must derive ultimately from the waste materials themselves.

The process of reconverting all wastes into useful nutrients requires a great complexity of organisms to accomplish the myriad subtle chemical transformations to complete nutrient cycles. Fortunately this intricate collection of organisms, driven by survival instinct, seizes on all possible opportunities not only to prey on other organisms or fix solar and biotic energy, but also to scavenge the wastes of others. Thus recycling aids and is aided by the constituent biota of the ecosystem. Logically, then, a stable ecosystem requires complete recycling of nutrients (unless an external source introduces them continuously) and a constant input of energy from without. It follows that equilibrium for an ecosystem is based on the cycling of a constant stock[5] of basic nutrients maintained by a continuous steady inflow of external energy to create a stable set of nutrient and biotic energy flows.

Recycling in an economic system also suggests the progression of a commodity through a phase of "useful economic life" terminated by obsolescence or breakdown. For such a used hulk to return to its "useful" phase as the originally desired commodity, a series of transformations must take place including waste collection, reprocessing and finally refabrication of the recycled materials into the original product. It also follows that for an economic system to maintain indefinitely a constant set of flows of useful goods and services from a given finite stock of non-renewable raw materials (assuming no losses of material in production and recycling processes) complete recycling must be resorted to in the long run.

In the short run, however, economies differ significantly from ecosystems in terms of immediate need to rely on recycling to maintain a given level of ouptut. First of all, economies do not now have as their primary goals the maintenance of some optimal long-run balance of human, animal and plant populations. Rather, economic goals focus on maximizing per capita benefits, where the "capita" represent only mankind. Therefore, the sizes of the other biotic populations will be manipulated to serve man. Hence, agriculture can be seen as man's purposeful tending of plants and animals to maximize the nutrient and raw material flows available to him. Secondly, economic systems as yet do not operate under the pressures of immediate resource limits that condition natural ecosystems. Stable ecosystems cannot rely substantially on "mining," though they do to a small extent, as plants serve to break down rocks and pull their minerals into the ecosystem initially. By contrast, not only can economies depend primarily on extracting virgin materials for a long time, they can also currently dispose of wastes on a throughput basis, storing them over large areas of land —something a stable ecosystem cannot or will not do.

Thus stable ecosystems, ensconced within tight internal resource limits, faithfully reproduce the same nutrient and energy flows indefinitely by full resort to recycling. Growth also proceeds in the context of complete recycling. Economies, on the other hand, continue to expand output by drawing ever more rapidly upon virgin resources rather than by recycling growing piles of waste materials. Whether this systematic bias towards throughput is economically optimal is a question that should be resolved.

The Economic Case for Throughput

That economic output and growth rests so heavily on the throughput-oriented use of non-renewable resources is surprising and perverse to the non-economist. Does not the market mechanism perceive that severe resource depletion and land encumbrance must come sooner without recourse to recycling? Let us here present the economic rationale for throughput, at least in the short run.

Consider Table 1 below. The choice as to whether throughput or recycling will be emphasized in the use of a given resource will depend on the totals of cost categories (1) + (2) + (3) + (4) + (5) for recycling and throughput respectively. Since costs of fabrication F_t and F_r are assumed equal for throughput and recycling[6] the choice made will depend on which of the following two expressions is greater, $V_t + R_t + W_t + S_t$ (throughput) or $R_r + W_r$ (recycling).

At this point we should complicate the analysis by bearing in mind that for commodities such as those made from iron, copper, lead, rare metals, glass and wood fibres a mixture of throughput and recycling activity takes place. Assuming that all decision-makers in the market were endowed with perfect information and that all markets indeed functioned well enough for all benefits and costs

TABLE 1

CATEGORIES OF COSTS ASSOCIATED WITH THROUGHPUT AND RECYCLING

Throughput	Recycling
(1) Costs of virgin resource extraction (including costs of seeking new sources and developing substitutes) (V_t)	(1) Nil.
(2) Costs of refining virgin resources and their subsequent processing costs (R_t)	(2) Costs of refining and processing recycled waste materials (R_r)
(3) Costs of fabrication (F_t)	(3) Costs of fabrication (F_r)
(4) Costs of waste collection, handling and disposal (W_t)	(4) Costs of waste sorting, collection and handling for reprocessing purposes (W_r)
(5) Costs of waste storage, compaction, incineration, etc. (S_t)	(5) Nil.

to be fully internalized by he who incurred them, we could argue that one hundred percent throughput and one hundred percent retrieval of wastes are judged inferior solutions to combinations of recycling and throughput activity. For example, 40 percent of all copper waste is recycled. This "market solution" could be interpreted as follows: given the technology available to us at the present, the spatial patterns of copper extraction, refining, fabrication and consumption dictate that 100 percent throughput would give rise to economic scavenging, with a host of dealers gathering bulk industrial scrap in particular for sale to copper refineries. This is possible because such spatially concentrated sources of easily recovered (pure) copper become far cheaper as a raw material for copper refining than virgin copper in the form of copper concentrate. However, private scavenging will not bring about the return of all waste copper because, for example, the cost of retrieving small copper components and wiring from discarded appliances would make recycled copper from that source prohibitively expensive, vastly exceeding the costs of copper from virgin sources. Thus, the more spatially dispersed, fine and impure the waste copper is, the more expensive it is to recycle. Hence the physical possibility of recycling does not always guarantee the economic desirability of recycling.

This analysis suggests that there exists some envelope curve of minimum total costs of copper use as a function of the degree of

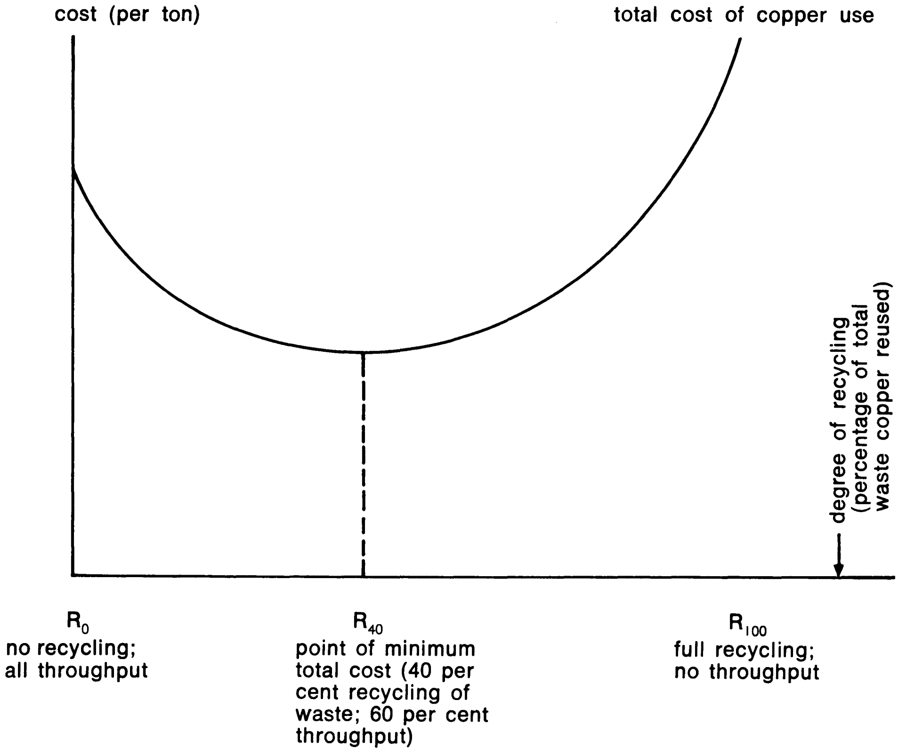

FIGURE 1
Theoretical Variation of Copper Use Costs with Degree of Recycling

NOTE: This curve describes variations in copper use cost with degree of recycling at a given point in time, that is, under given conditions of natural resource availability, extraction and refining technology, cost of land use for waste disposal and storage, and technological conditions affecting recycling activities. Thus, with any change in the above parameters, the curve will shift, particularly with regard to its minimum cost point. It is logical to predict that in the long run the minimum point must shift to the right (and upward), since copper is a non-renewable resource.

recycling, as depicted in Figure 1. Similar hypothetical cost curves could be drawn for other raw materials. In this case, the curve reaches its minimum at the point R_{40}, at which an optimal mix of recycling and throughput technologies are being put to work consistent with 40 percent recycling of wastes.

Although for certain metals recycling-component values ranging from R_{25} to R_{40} exist (iron, copper, lead), and R-values approaching 100 percent in the case of rare metals (gold, silver, platinum)[7] are theoretically possible, many of the cheaper raw materials in our economy experience recycling coefficients between R_0 and R_{10}. This is to say that beyond recovery of the cheapest 10 percent of waste (usually bulk industrial scrap) the marginal cost of a percentage point increase in recycling activity exceeds the marginal cost reduction accomplished by the one percentage point reduction in throughput activity.

If we examine the cost categories we have enumerated for recycling and throughput activities, the reasons for our heavy throughput emphasis can be found. Consider categories V_t and R_t from Table 1, the costs of bringing virgin resources into the economic system. Extraction costs for mineral and renewable resources have been historically low throughout the Industrial Age (1800 onwards). Up to now decreasingly favorable geological conditions of ore concentration and spatial accessibility have been more than offset by declining costs of extraction and refining activities thanks to rapid technological progress and an abundance of fossil fuels. Secondly, S_t and W_t, costs of waste collection and disposal, have remained historically low, not only because of the cheapness of fossil fuels for waste transportation, incineration and compacting, but also because of abundant land (at least in this country) near population centers for waste disposal.

These two factors, abundant land and cheaply available virgin resources have been pivotal in orienting technological development pervasively towards throughput-oriented activity. Without any economic feedback arising from land, mineral or biotic resource depletion, R_r and W_r technologies were historically badly neglected, allowing their relative costs to rise with respect to V_t, R_t, W_t and S_t costs.[8] Although we assumed that $F_t = F_r$, it could be argued also that since convenience (time-saving) is a much sought-after economic entity, disposable commodities are preferred to non-disposable ones, and therefore fabricating costs could be reduced for disposable items in the form of throwaway bottles with less glass content, thin metal cans with non-recyclable impurities, and not-so-durable consumer durables. Hence, as things stand now, F_t may well be less than F_r for most resources. Finally, the costs of waste sorting have also been allowed to remain high because refuse is collected in mixed form and is therefore expensive to separate into recoverable components. Pre-sorting or post-sorting drives up W_r as opposed to W_t which requires no sorting of trash.

The Economic Rationale for Recycling

Such is the economic justification for the small degree of recycling that takes place in our economy. There is also an economic rationale for questioning this high level of throughput, particularly if our implicit economic assumptions, perfect knowledge and full internalization of costs and benefits, are brought into question. First, let us consider the resource availability future as depicted by leading geologists and energy economists. In particular, the seminal research by Hubbert with regard to energy availability[9] and by Lovering concerning metals availability[10] presents a convincing warning to us that the relatively cheap virgin resource ride is about over. Hence in the future the vastly higher costs of extracting and refining remaining virgin resources will shift economic activity much more in favor of recycling than is presently the case. This would seem to be a perfectly natural economic adjustment to changing market circumstances; however, we are not guaranteed a frictionless transition to a recycling age just on the basis of existing market mechanisms. The past neglect of recycling-oriented use patterns and technology might well cause the degree of recycling to increase less than optimally. Such a lag effect could cause severe economic disruptions in the supply of key minerals.

Secondly, there is a good case for arguing that manufacturers and consumers are not being faced with the full costs of their throughput-oriented production and consumption patterns in terms of land use for waste disposal. In most communities refuse collection services are funded out of general municipal revenues; households are not charged in accordance with the individual amounts of refuse they generate. Hence the consumer, and secondarily the manufacturer, face no direct incentive to cut down on waste creation. Moreover, solid waste accumulates year after year, unlike most air and water pollutants. Thus, the marginal costs of its disposal mount, as increasing waste presses its insatiable demands on a fixed factor of production. At the same time economic growth means increased spatial demands by all sectors of the economy. Since all activity requires space, and space accessible to population concentrations is physically limited, such increasing spatial competition raises land prices greatly, thus magnifying the opportunity costs of utilizing land for waste disposal over what the opportuniy costs would have been under conditions of a non-growth economy with throughput. Without a built-in price mechanism to charge people in accordance with the volume and treatability of the refuse they discard, such throwaway commodities will continue to be produced without regard to the increasing land costs of their disposal.

Economic Incentives for Recycling

There is thus a substantial case for promoting more recycling in our economic system. However, moral exhortations and voluntary recycling drives may have only temporary and sporadic effectiveness; crude political directives to force manufacturers to stop disposal-oriented output may provoke a sympathetic public backlash in their favor, allowing them to repeal, amend, or avoid such legislation through lobbying. Instead, milder but more persistent solutions which tax throughput and subsidize both recycling activity and research into recycling technology are more attractive to the economist.

Taxes

The most logical throughput tax would be one on actual waste-creating activity itself. Accordingly one's volume and type of trash would determine the amount he would be assessed. However, metering trash is not practicable; instead, solid waste creation will have to be attacked indirectly by taxation and subsidy with respect to throughput and recycling-oriented production.

Before examining what our tax and subsidy policy should be, we shall start from the economic premise that for every tax an equivalent subsidy or subsidy-plus-tax combination can be found with the same reallocative effects on output patterns. Hence to simplify our discussion we shall deal exclusively with taxation. The reallocations incurred will have benefits and costs. Taxing[11] throughput will both reduce pressure on certain virgin resources and free land that would have to be otherwise appropriated for refuse disposal. On the other hand, its costs would appear in the form of increased personal effort to handle and sort waste, return bottles, etc., and increased social costs of collecting, sorting and reprocessing waste materials.

At what level should the tax be set? First, let us approach the question in general terms. If we grant that a recycling tax is to be set at all, then it can be argued that the marginal benefits of the tax must exceed its marginal costs when the tax is zero. Logically it follows that the tax rate should be set so that its marginal social benefits are equal to its marginal social costs. For example, any consideration of rent gradients and neighborhood differences in land values will make it clear that land does not have a uniform price. Assuming a municipality at all times is trying to use land with the least opportunity costs, it will find itself forced to utilize land of increasing economic value as its solid waste burden continues to mount. Hence, were its refuse disposal need reduced, the marginal cost of land for waste disposal would decline accordingly.[12] The marginal benefits of ameliorating future resource availability crises might similarly drop as the throughput tax was raised, although by how much is uncertain. On the other hand, marginal costs of such a tax are certain to rise. At first the tax will flush out industrial scrap and other forms of bulk waste relatively cheap to gather and reprocess. At higher levels, the tax would induce much more expensive recycling activity, as the marginally harvested sources of waste material became ever more mixed, geographically scattered, and chemically impure.[13] Thus, beyond some optimal level the tax's marginal social costs would exceed its marginal social benefits.

A uniform *ad valorem* tax for all goods will not take into account the differences between commodities in terms of their solid waste burdens. For example, gold production involves no throughput at all; a tax is therefore superfluous on recycling grounds. By comparison, paper production creates an immense solid waste burden and might well be subject to a fairly high tax. Furthermore, a resource like iron is never economically junked because of the large number of heavy manufacturers waiting to process it. Hence, basic steel manufacturing is hardly deserving of the throughput tax. Steel beer cans, by way of contrast, are highly susceptible to disposal and should be taxed accordingly.

Thus, throughput taxes should be levied primarily on the following basis: the amount of waste created per dollar's output of the commodity involved would be determined and weighted by a composite of factors including incineration and compacting costs per ton, if these result in significant space savings in disposal.

Having stated the need for a recycling tax system, we should turn to certain distortions in existing tax and rate structures which encourage throughput over recycling. For example, iron ore should not enjoy a railway rate preference over scrap iron; each should be charged according to actual transfer costs incurred.[14] Secondly, depletion allowances represent a questionable practice, particularly with respect to renewable resources such as forests and non-renewable but recyclable materials such as metals.[15] However, extraction of virgin materials is not necessarily a solid waste-creating activity in the conventional sense; rather such costs are more typically embodied in damage to wilderness retreats and should call forth taxes on those grounds. Although depletion allowances discourage recycling by reducing the cost of virgin resources as compared to recycled materials, they encourage increases in our total metals-in-use stocks, allowing economic growth both under throughput conditions in the short run and under predominantly recycling conditions in the long run.[16] However, an increase in depletion allowances, while causing more rapid growth in metals-in-use, would further discourage recycling. Moreover, it would further distort energy use in the direction of refining ever more difficult to process virgin ores. On the other hand, an extraction tax, while promoting recycling, will also stem the growth of metals-in-use stocks and inhibit economic growth as a side effect.[17] Thus, except under special circumstances there should be neither a depletion allowance nor an extraction tax; both usually cause unnecessary distortions in patterns of metals extraction, use and recycling. Whatever recycling effects can be generated by an extraction tax can be equalled with fewer undesirable side effects by a specific tax on derivative commodities.

Subsidies

Since taxes are onerous to consumer and businessman alike, a combination of taxes and subsidies might be preferred politically to a tax-only system to encourage recycling.[18] Use of recycling subsidies in concert with throughput taxes would first of all reduce the tax rates required to induce the optimal amount of recycling. Secondly, recycling subsidies payable to whomever recovered the waste materials would increase not only the frequency of voluntary recycling drives on the part of charitable institutions but also permanently establish a growing infra-structure of firms and individuals engaged in the collecting of waste materials. Both as an inducement to recycling activity and as a statistical check on the disbursements of recycled materials, the government should set up an extensive network of recycling stations, to pay those who turn in waste materials, and to sell recoverable materials in turn to manufacturers. Finally, there is a wide variety of research topics concerned with realigning manufacturing and packaging technologies so as to make each sector of the economy mesh more efficiently with the others in order to secure decreases in waste creation consistent with the same levels or increases in economic output.[19] Such investigations deserve governmental support.

CONCLUSION

For political and economic reasons recycling will soon become an increasingly important phase of economic activity. It represents the solution to both the problems of increasing solid waste with its attendant insatiable demands on land and those associated with the growing scarcity of natural resources. In the long run economic growth will become fundamentally linked to improved retrieval of waste materials whose virgin counterparts are largely depleted; thus an almost complete recycling economy will approach the equilibrium of a stable ecosystem, hopefully with more per-capita benefits than subsistence rations.

FOOTNOTES

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[1] Brown, H., *Human Materials Production as a Process in the Biosphere, Man and the Ecosphere* (San Francisco: Freeman, 1971) 113. According to Brown, 40% of steel is recycled in the form of scrap, a figure that may be too high. A similar figure is quoted for copper recycling. U.S. Bureau of Mines, MINERAL FACTS AND PROBLEMS (Washington, D.C.: Government Printing Office, 1970) Vol. I.

[2] Throughput describes economic and biological activity that removes wastes once and for all from the overall sphere of activity in question. Hence biological wastes are excreted from the bodies of individual organisms, and are not reabsorbed by the same organism or organism type. Similarly, wastes from economic consumption and production leave the market place as undesirable materials with negative prices. Their fate is the city dump, slag heap, incinerator, etc.

[3] *See, e.g.,* D. Meadows, *et al.,* THE LIMITS TO GROWTH (Washington, D.C.: Potomac Associates, 1972).

[4] E. P. Odum, FUNDAMENTALS OF ECOLOGY, 2nd ed. (Philadelphia: Saunders, 1959) 10–42; G. L. Clarke, ELEMENTS OF ECOLOGY (New York: Wiley, 1954) 16; both quoted in W. Israel, *et al.,* ECOLOGIC—ECONOMIC ANALYSIS FOR REGIONAL DEVELOPMENT (New York: Free Press, 1972) 51.

[5] The difference between "stock" and "flow" concepts should be

clarified. A stock concept is one without a durational time dimension; it refers to a volume at an instant of time. For example, the volume of phosphorous in a marshland represents a stock concept. On the other hand, flow concepts have a durational time (or other) dimension; for example, the amount of phosphorous ingested annually by the marshlands seagull population is a flow concept, as is the amount of solar energy fixed annually by the marshland's plant population.

[6] This is an arguable assumption, as will be discussed below.

[7] In actual fact most gold extracted is not recycled, not because it is uneconomical to recover, but because it goes into such uses as jewelry which wear out extremely slowly, if at all. Hence gold use represents a transformation of gold from virgin metal to metal-in-use not as yet followed by a significant recycling phase. Other metals such as iron not only have an important recycling loop, but also a far greater waste throughput stream.

[8] Such technologies were historically labor-intensive. Examples were junkmen and rag-pickers. Hence rising labor costs not offset by labor-saving innovations (as took place in throughput operations) raised the costs of waste scavenging as opposed to disposal costs.

[9] M. K. Hubbert, *Energy Resources,* National Academy of Sciences, National Research Council, RESOURCES AND MAN (San Francisco: Freeman, 1969), 157–242.

[10] T. S. Lovering, *Mineral Resources from the Land,* National Academy of Sciences, National Research Council, RESOURCES AND MAN (San Francisco: Freeman, 1969) 109–134.

[11] The tax would have to be levied on a nationwide scale to prevent bootlegging.

[12] This present argument is framed in a static context.

[13] The fact that many waste materials were manufactured in such a way as to make recycling very difficult attests to the overwhelming strength of the throughput orientation in our economy.

[14] The head of the Environmental Protection Agency, William Ruckelshaus, stated "we are going to have to stop subsidizing virgin (new) materials use and take steps to assure that secondary (recycled) materials can compete on an equal footing." "Agency Urges Incentives to Re-Use Solid Wastes," New York Times, Feb. 4, 1973, p. 1. He was referring to preferential haulage rates given to virgin materials over scrap.

[15] Fuel depletion allowances are not discussed here because such energy sources cannot be recycled after use.

[16] The real economic rationale (if there is one) for depletion allowances is that they are required if the economy is to engage in the optimum amount of extraction activity. Otherwise, given the risks of prospecting, insufficient entrepreneurship will be directed into explora-

tions for virgin materials. With regard to energy use, since more energy is expended to extract virgin copper than to reprocess assembled recycled copper, the cost of extra energy use associated with virign materials extraction induced by depletion allowances is presumed to be outweighed in terms of increased benefits to the rest of the economy through the expansion of metals-in-use.

[17] As pointed out before, economic growth and recycling are not incompatible; rather, recycling permits economic growth by allowing greater annual output from a given metals stock.

[18] In fact a subsidy may be essential to induce recycling in some cases. In the case of paper, the demand in the aggregate is highly inelastic; therefore, a heavy throughput tax on paper will not significantly reduce consumption. Hence the potential solid waste burden remains almost as great as if no tax were levied in the first place. Secondly, if the paper tax is set high enough, the institutions akin to "stills" might begin to manufacture illicit paper.

[19] For examples, *see,* W. Litsky, H. Gunner, and R. Kreplick, ed., NEW DIRECTIONS IN SOLID WASTES PROCESSING: PROCEEDINGS OF AN INSTITUTE HELD AT FRAMINGHAM, MASSACHUSETTS, MAY 12–13, 1970 (Amherst: Technical Guidance Center for Industrial Environmental Control, University of Massachusetts, 1970).